NASA TECHNICAL MEMORANDUM

NASA TM X- 62,416

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(NASA-TM-X-62416) HEADS UP DISPLAY FOR THE FLIGHT SIMULATOR FOR ADVANCED AIRCRAFT (FSAA) (NASA) 16 p HC $3.25 CSCL 14B

N75-24761

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HEADS-UP DISPLAY FOR FLIGHT SIMULATOR FOR ADVANCED AIRCRAFT (FSAA)

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January 1975

1. Report No. NASA TM X-62,416	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle HEADS-UP DISPLAY FOR THE FLIGHT SIMULATOR FOR ADVANCED AIRCRAFT (FSAA)		5. Report Date
		6. Performing Organization Code
7. Author(s) David H. Brocker and Bruce C. Ganzler		8. Performing Organization Report No. A-5959
9. Performing Organization Name and Address NASA Ames Research Center Moffett Field, Calif. 94035		10. Work Unit No. 760-72-06-03
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C.		13. Type of Report and Period Covered Technical Memorandum
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A heads-up flight director display designed for a V/STOL lift-fan transport simulation study is described. The pilot's visual flight scene had the heads-up display optically superimposed over the usual out-the-window, video flight scene. The flight director display required the development and integration of a flexible, programmable display generator, graphics assembler, display driver, computer interface system, and special collimating optics for the pilot's flight scene. The optical overlay was realistic because both scenes appeared at optical infinity, and the flexibility of this display device establishes its value as a research tool for use in future flight simulation programs.

17. Key Words (Suggested by Author(s)) Display devices, Heads-up display, Graphic system, Simulation, Television visual simulation, Cockpit instrumentation		18. Distribution Statement Unclassified - Unlimited STAR Category 06	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 16	22. Price* $3.25

*For sale by the National Technical Information Service, Springfield, Virginia 22151

HEADS-UP DISPLAY FOR THE FLIGHT SIMULATOR FOR ADVANCED AIRCRAFT (FSAA)

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SUMMARY

A V/STOL lift-fan transport flight simulation project using the Flight Simulator for Advanced Aircraft at Ames Research Center required the addition of a heads-up flight director display. The pilot's visual flight scene had the heads-up display optically superimposed over the usual, out-the-window, video flight scene. The flight director display required the development and integration of a flexible programmable display generator, graphics assembler, display driver, computer interface system, and special collimating optics for the pilot's flight scene.

INTRODUCTION

The Simulation Sciences Division of Ames Research Center is engaged in manned flight simulation using simulators such as the Flight Simulator for Advanced Aircraft (FSAA) shown in figure 1 and reported in reference 1. This facility, in operation since 1969, has the capability of high-fidelity simulation of a large range of flight vehicles. The FSAA complex includes a large-scale, six-degree-of-freedom motion simulator; a Visual Flight Attachment (VFA) that consists of a color television camera viewing a scale model of terrain and runway; an out-the-window, infinity-focused flight display; and an extensive digital computer system. The simulator's most dramatic feature is its unique 100 ft of lateral travel.

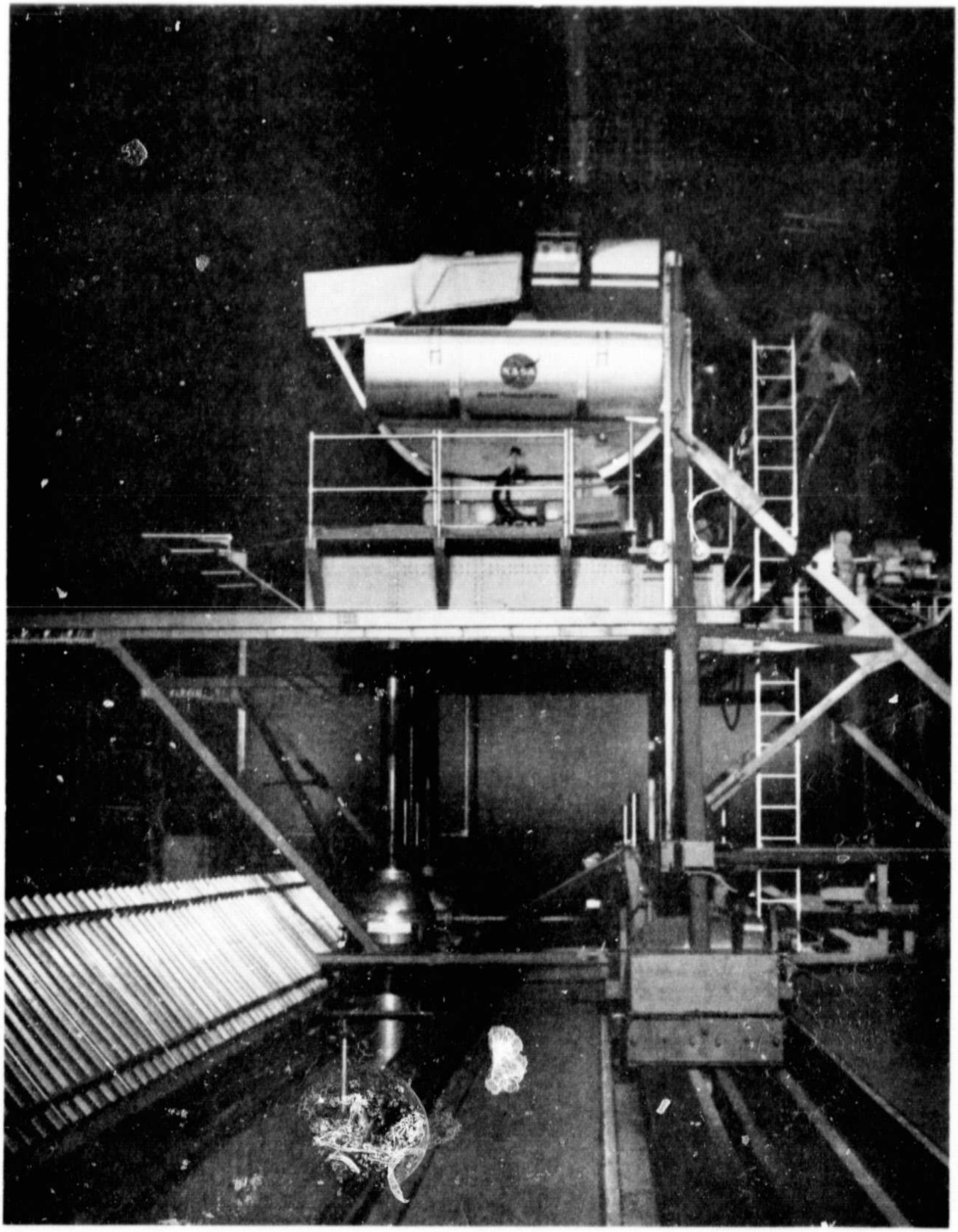

Figure 1.- Flight simulator for advanced aircraft (FSAA).

The FSAA system is used in a closed-loop manner with the computer program responding to pilot control inputs, as though it were the aircraft under study, by solving the mathematical equations that comprise the aircraft model. A diagram of the various systems that comprise an FSAA simulation is shown in figure 2. The pilot, located in the simulator cab, observes the state of the aircraft through the use of motion cues, a control force-feel system, flight instruments, sound cues, and the VFA scene. The pilot "flies" the aircraft by actuation of flight controls that are representative of the flight vehicle under study. The computer system monitors all pilot control actions, solves the aircraft model equations, and drives the pilot cue systems. In this manner, a closed-loop, real-time simulation of complex aircraft is achieved.

A program was started in 1973 to study the control aspects of a lift-fan vehicle on the FSAA simulator (refs. 2 and 3). One of the requirements for this program was a special flight director display. The pilot's visual flight scene was to include a heads-up display (HUD) that had to be superimposed over the VFA scene. The HUD was to provide the pilot with visual, out-the-window, flight-control information that appeared in the same image plane as the simulated runway flight scene.

REQUIREMENTS

The HUD's symbology and format are shown in figures 3 and 4. The lift-fan vehicle required that the HUD provide specific picture information; however, it was decided that a flexible, programmable display generator would be more useful in meeting future HUD requirements. This flexibility is desirable because the FSAA is a research tool for investigating a variety of manned flight vehicles.

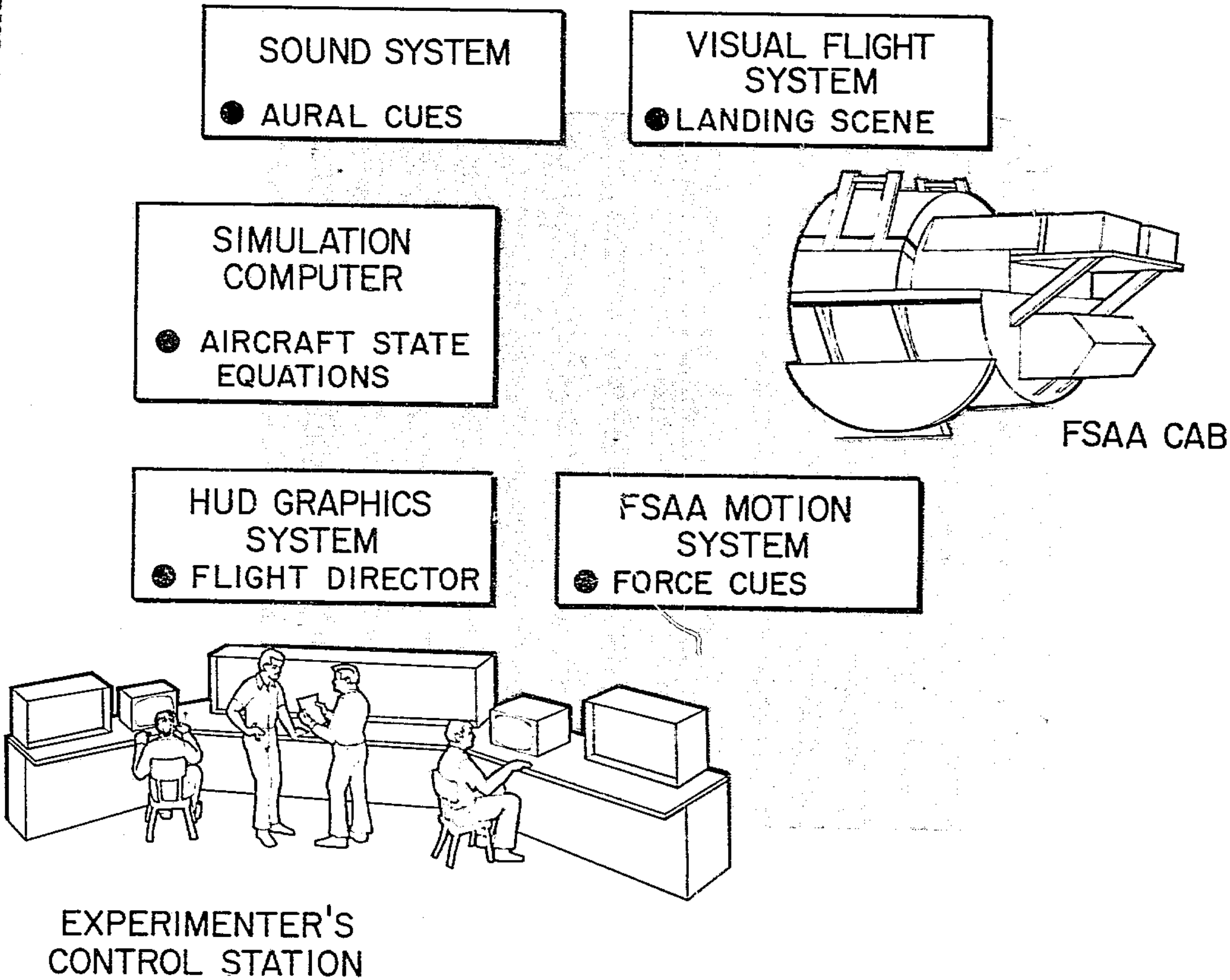

Figure 2.- Flight simulator for advanced aircraft system with heads-up display.

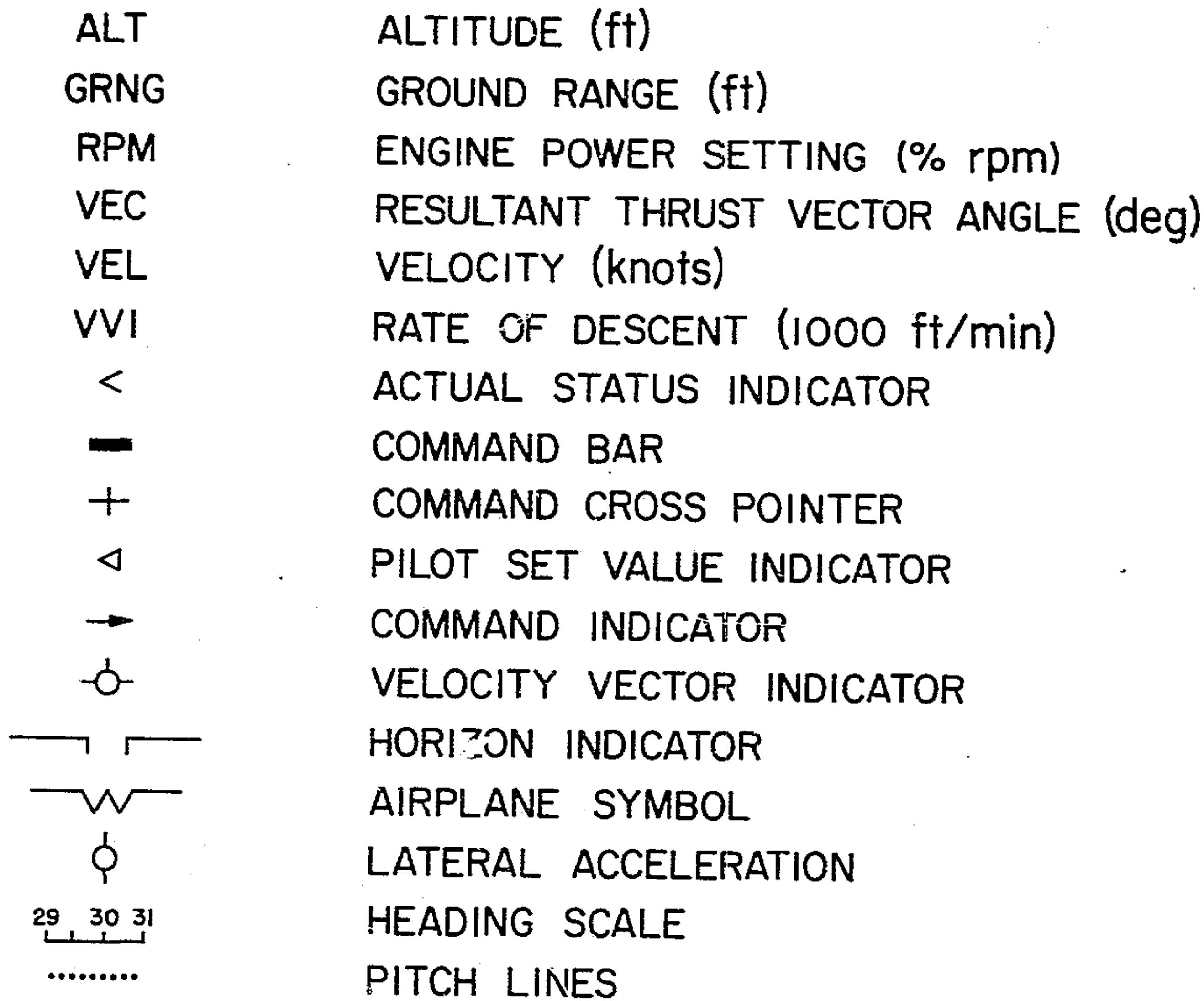

Figure 3.- Heads-up display symbols.

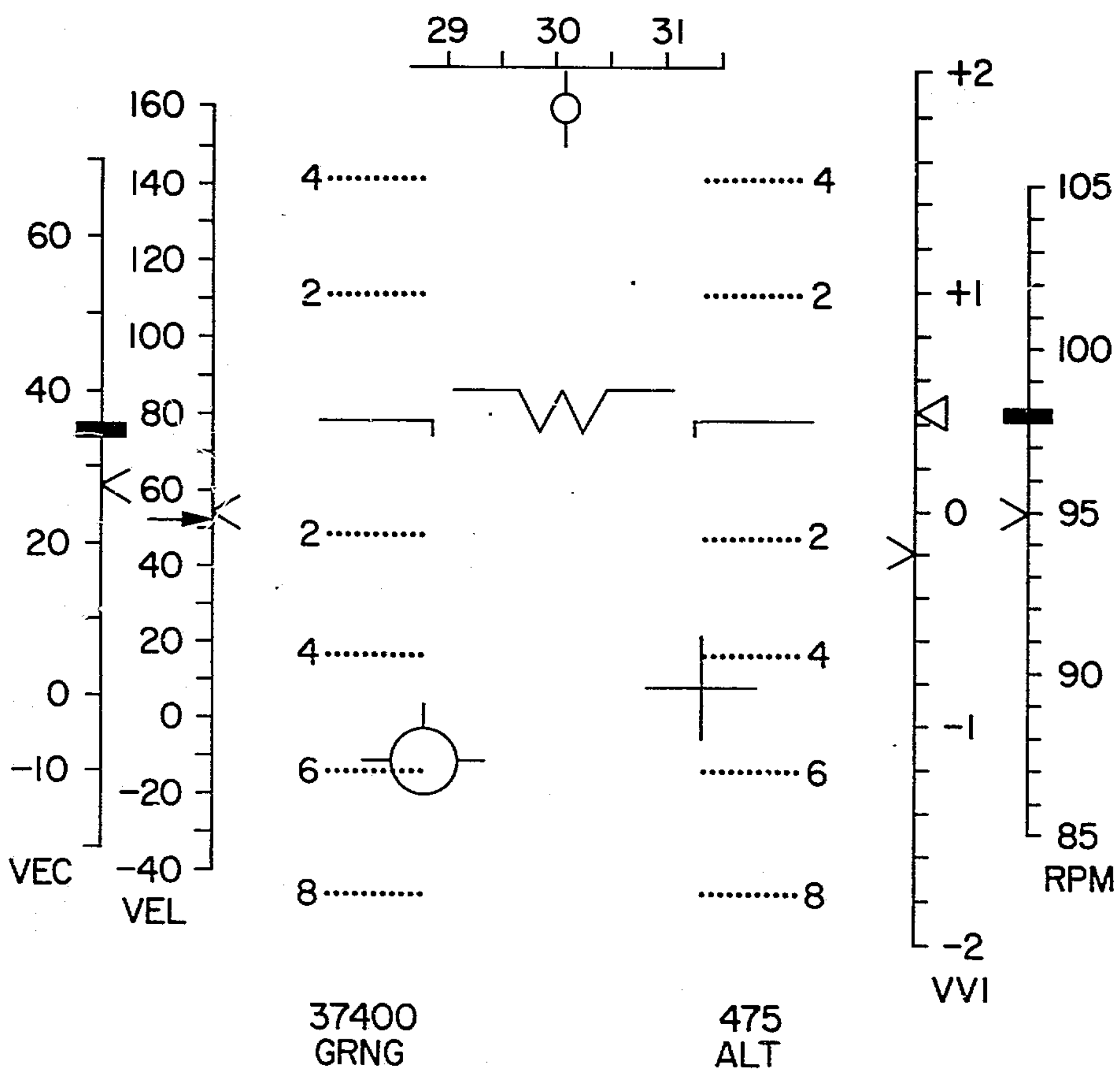

Figure 4.- Heads-up display format.

An additional requirement for the HUD system was that the display generator had to be a separate, stand-alone computation element within the computer laboratory. This requirement was necessary since the simulation computer, used in the solution of the aircraft dynamics, would not be available to do much more than to format and transmit aircraft status data needed by the HUD graphics system. Also, the interface between the two computers had to be designed with intermediate storage so that both computers could work autonomously.

Because of the requirement to superimpose the flight director graphics over the VFA scene, the HUD system had to be a line (vector) and character drawing system as opposed to a raster graphic system. This was necessary to have the HUD picture overlay the VFA scene without unnecessarily blocking it and to eliminate the "tearing" that occurs when lines drawn on raster systems are rotated at angles near the direction of the raster itself. The optically combined HUD and VFA pictures must take into consideration the parallax problem encountered when simulated flight scenes are displayed close to the pilot's eyes. This dictates the use of a collimating optical system that will ensure that the HUD and VFA pictures are focused at optical infinity (30 m or more).

Two additional flight director displays were required to monitor the simulation: one display was located at the cab instrument panel and the other at the experimenter's control station.

HUD Graphics System Configuration

The solution of the HUD problem included the acquisition of a small display computer, remote displays, an optical combiner, interface to the FSAA control computer, and an interface to the Ames Central Computing Complex. Figure 5 is a block diagram of this system.

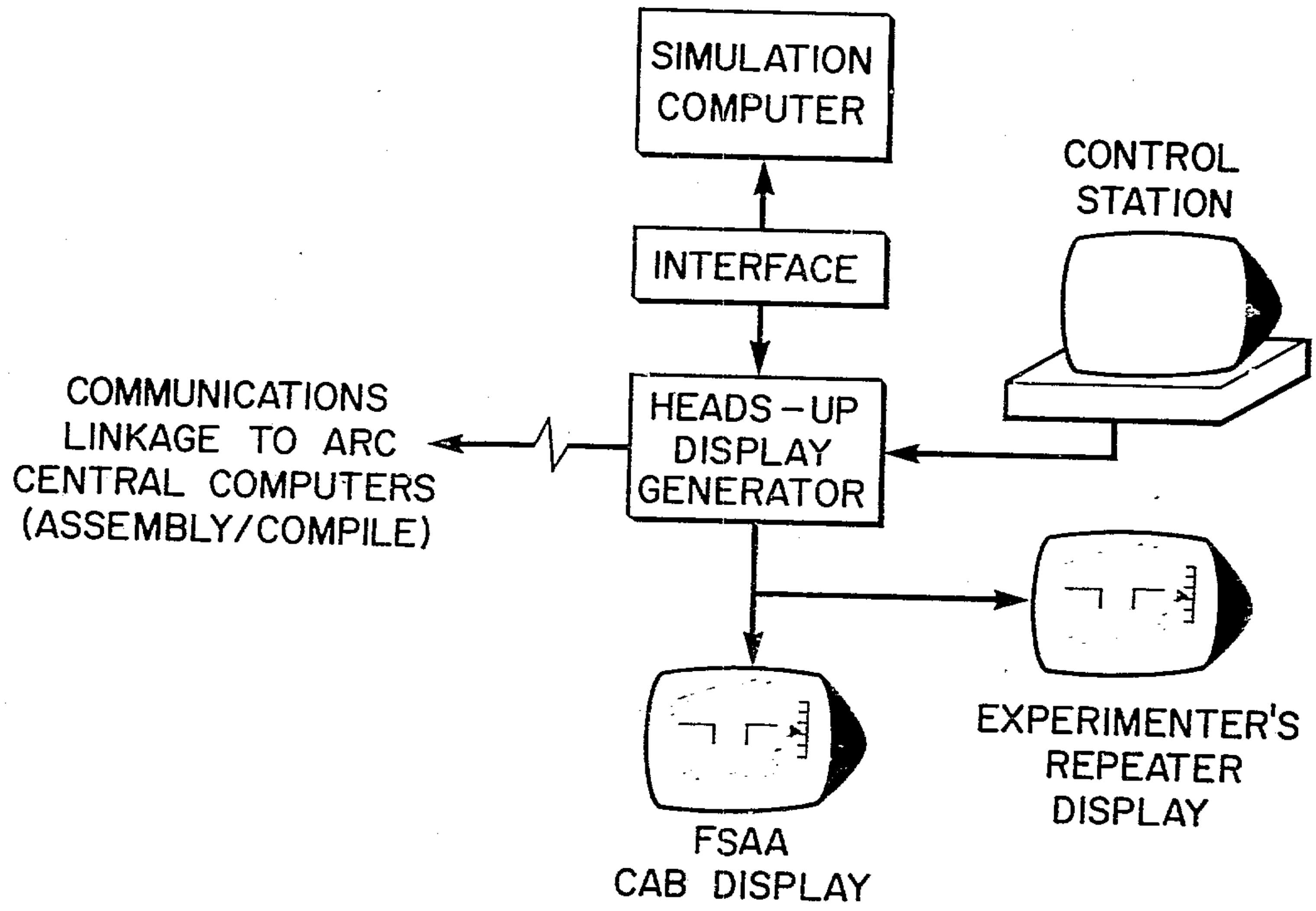

Figure 5.- Block diagram of HUD generator.

The display computer is a small, special purpose processor that includes hardware and instructions for the generation of a calligraphic (line) picture on cathode ray tube (CRT) display devices. The unit selected was an IMLAC PDS-1. It is a 16 bit/word processor with a memory space of 8192 words. Specific details describing the architecture, instruction set, and performance can be found in the IMLAC manual (ref. 4).

A graphics assembler was developed at Ames for IMLAC program development on the Ames Central Computing Facility, an IBM-360 operating under the IBM time-sharing system. Programs were typed into the IMLAC memory, transferred to the IBM-360 via a phone line communications interface, assembled, and saved. When the user was ready to begin operation, he requested that his binary object program be loaded into the IMLAC from the IBM-360. Program execution could then proceed normally.

The display computer is also connected to the digital simulation computer, a Xerox Sigma 8, through a digital-to-digital interface. The Sigma 8 solved the aircraft equations of motion and transmitted the aircraft state to the display computer via this interface. The interface design was such that the Sigma 8 could transmit a block of data (up to 64 words) into an intermediate memory contained in the interface and trigger the IMLAC to inform it of the new data. The IMLAC then read these data, updated the picture data base, and issued a new display generation refresh command. In this way, each computer operated autonomously and minimized the time lost in operating the interface.

A display driver system was fabricated to provide a capability of driving multiple remote displays: one at the experimenter's control station and two in the FSAA cab. Distances involved in this specific application were

approximately 30 m to the experimenter's station and 250 m to the cab. No appreciable degradation of the picture or excessive noise were evident over this distance; however, careful line buffering and termination were necessary to accomplish this.

Program

The IMLAC program was written in assembly language. The display computer hardware automatically refreshes the picture from the picture data base once a start command is received, thus freeing the central processing unit (CPU) for other operations. Therefore, the program was separated into two specific areas: input of the new aircraft state data with subsequent updating of the data base and picture refresh control. The picture data base was double buffered so that the refresh unit could access one area while the CPU updated the other. In addition, the HUD picture was separated into elements (e.g., pitch lines, velocity scale, and indicator) to simplify the update process and protect against a partially updated functional element misleading the pilot.

The program utilized an internal 40-Hz clock for refresh synchronism. At this rate, using a P31 phosphor, the picture had some degree of flicker. It has been determined through subsequent use that a P45 CRT phosphor would reduce picture flicker without introducing excessive smearing of moving picture elements. The computer has 30-, 40-, and 60-Hz clock rates available, thus allowing some degree of tailoring with the program as well. One could also operate the refresh function without synchronism to a clock; however, special programming would be needed to ensure against a flickering display.

DISPLAY APPARATUS

The display apparatus for the out-the-window flight scene consisted of two television (TV) monitors, two plano-convex lenses, and a beamsplitter. The direct-view flight scene was displayed on a 21-in. color TV monitor. This VFA scene is produced by moving, through a servomechanism, a color TV camera over a scale model of terrain and runway. The picture, as viewed by the camera, is relayed by cable to the TV monitor located in front of the cockpit windscreen. The stroke-written HUD display was generated on a 16-in. CRT monitor. A similar CRT was installed in the pilot's instrument panel for a heads-down display of the HUD symbology only.

The two plano-convex lenses were mounted at the pilot's windscreen. These lenses provided the pilot with a collimated (virtual image) display. A beamsplitter was positioned at a 45° angle between the lens system and direct-view TV monitor. A circular polarizer was placed over the faceplate of the HUD TV monitor for reflection suppression and apparent reduction of objectionable image flicker.

OPTICAL SYSTEM

Virtual images in flight simulation displays are used because they provide the simulator pilot with a feeling of depth when he views an out-the-window TV flight scene. When large-diameter and long-focal-length plastic lenses are utilized, TV monitors can be used to display a suitable virtual image of the flight information (ref. 5).

The HUD can be optically superimposed on the direct-view flight scene if a beamsplitter is positioned between the lens combination and direct-view TV monitor. Both TV monitors are positioned at the focal point of the lens

combination. This results in a virtual image of both scenes appearing at optical infinity. The beamsplitter folds the path of the HUD image so that it will not interfere with the direct-view display. Because the beamsplitter can both reflect and transmit light rays, the pilot can view the two displays simultaneously in the same image plane. Figure 6 shows the physical relationship between the HUD and direct-view flight scene.

The virtual image of both flight scenes can be properly positioned by use of a calibrated camera range finder. A more precise method is to use a diopter telescope. When the object (TV image) is positioned at the focal point of the lens system, the diopter telescope will indicate a zero power reading. If the image is truly collimated, there is no movement of the image with respect to the diopter crosshairs as one moves his eye while viewing through the instrument. A television crosshatch pattern is used as the viewing scene to calibrate the required image distance.

The beamsplitter for this project had to be highly transmissive in order for the pilot to observe the direct-view color TV flight scene with sufficient brightness. In the reflective mode, the beamsplitter had to reflect a one-color (green) image of the HUD. The HUD had greater control of the brightness range; therefore, the beamsplitter's reflectance could be much lower than its transmittance.

Since the direct-view display contained a full spectrum of colors and had limited brightness, it was necessary to obtain a beamsplitter that did not limit any wavelengths in the visible region of the spectrum and at the same time transmit as much light as possible. This required the beamsplitter to have a multi-dielectric coating with a neutral spectral transmission.

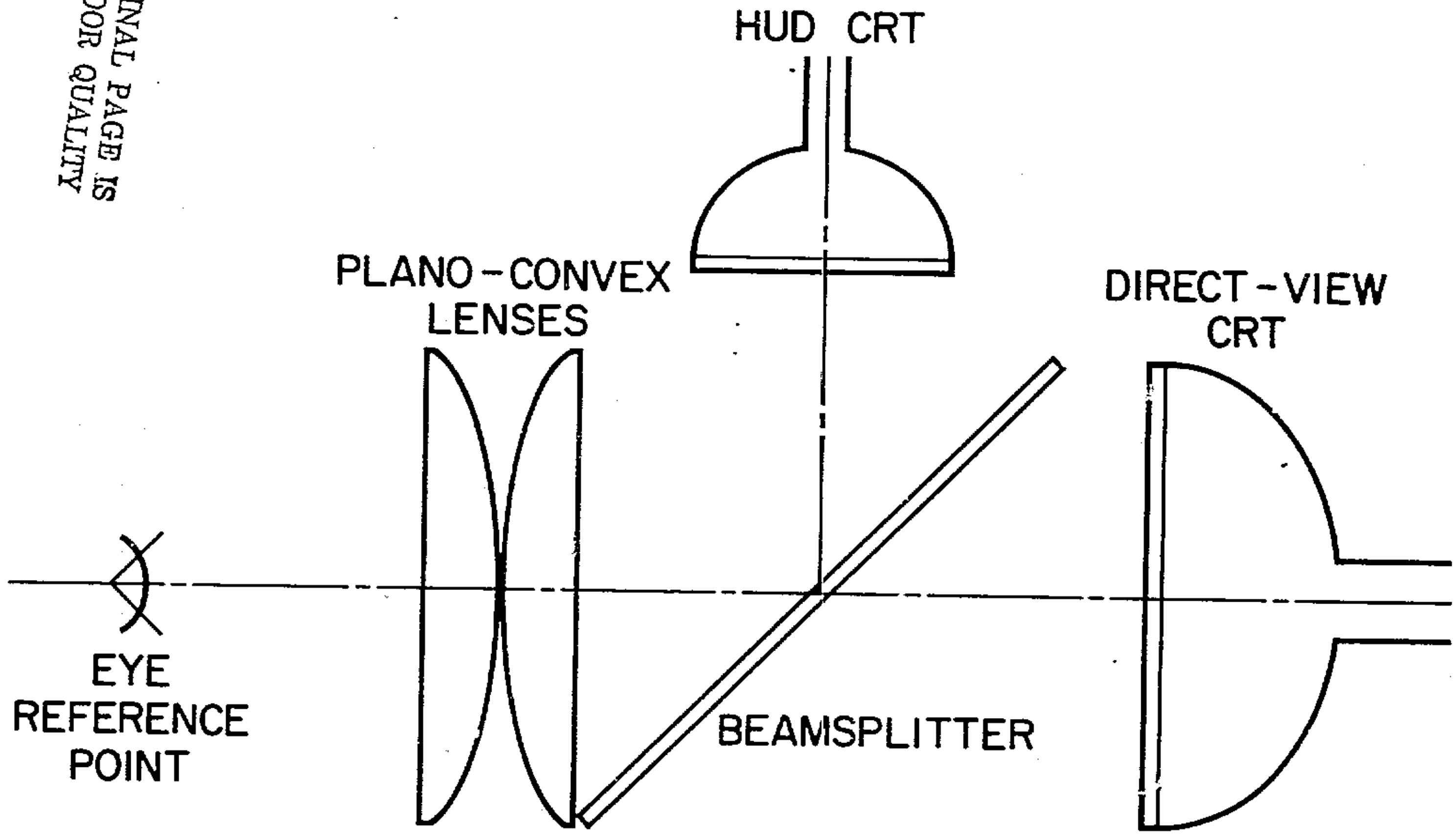

Figure 6.- Physical relationship between the HUD and direct-view flight scene.

The beamsplitter used for this project had a light transmission of 67 percent and a reflectance of 33 percent between the wavelengths of 450 to 650 nm. A single-layer antireflective coating (magnesium flouride) was applied to the opposite face from the beamsplitter coating. The size of the beamsplitter was 56 cm by 61 cm by 1.3 cm and made from plate glass. The beamsplitter provided sufficient light energy for comfortable viewing of the combined scene by the pilot.

CONCLUDING REMARKS

A heads-up display was designed for a V/STOL lift-fan transport flight simulation study. The equipment and programs developed for this simulation provided an effective method for presenting an out-the-window flight director display. The optical overlay of the heads-up display on the pilot's normal visual flight scene was very realistic since both scenes appeared at optical infinity. The flexibility of this display device has shown its value as a research tool for future simulation programs.

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